

Slides: <https://github.com/pdp7/talks/blob/master/oshw-bof-lfelc-pdx-2018.pdf>

Open Source Hardware

**“Birds of a Feather” (BoF) session at
Embedded Linux Conference 2018 in Portland**

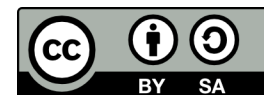


Drew Fustini

OSH Park

drew@oshpark.com

[@oshpark](#) / [@pdp7](#)





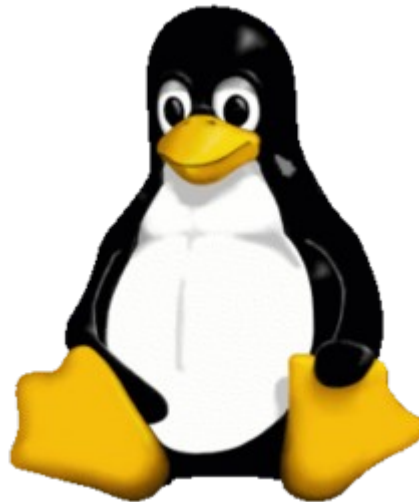
What is Open Source?



- Examples of popular Open Source projects



Apache



LibreOffice®



Firefox®



What is Open Source?



- The term "**open source**" refers to something people can **modify and share** because its design is **publicly accessible**
- **Open Source software** is software with source code that anyone can:
inspect, modify, and enhance



What is Free Software?



A program is free software if the users have **four essential freedoms**:

- 1) run the program as you wish, for any purpose
- 2) study how the program works, and change it so it does your computing as you wish
- 3) redistribute copies so you can help your neighbor
- 4) distribute copies of your modified versions



Open Source Hardware



- **FLOSS** is a term to describe software that is **Free**, **Libre**, or **Open Source Software**
- In the context of hardware projects, I consider these terms equivalent:
 - Free Hardware
 - Libre Hardware
 - Open Hardware
 - Open Source Hardware



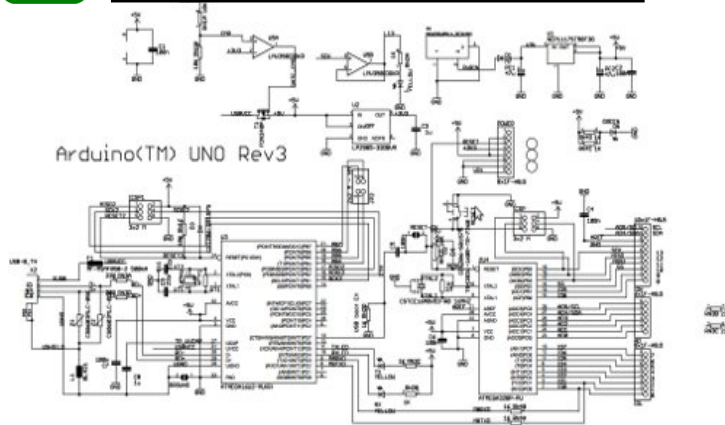
Statement of Principles:

Hardware whose **design** is made **publicly available** so that anyone can **study**, **modify**, **distribute**, **make**, and **sell** the design or hardware based on that design

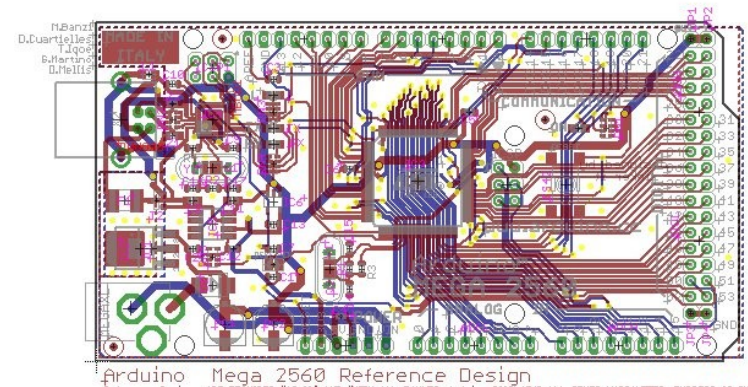
Open Source Hardware

Documentation required for electronics:

✓ **Schematics**



✓ **Board Layout**



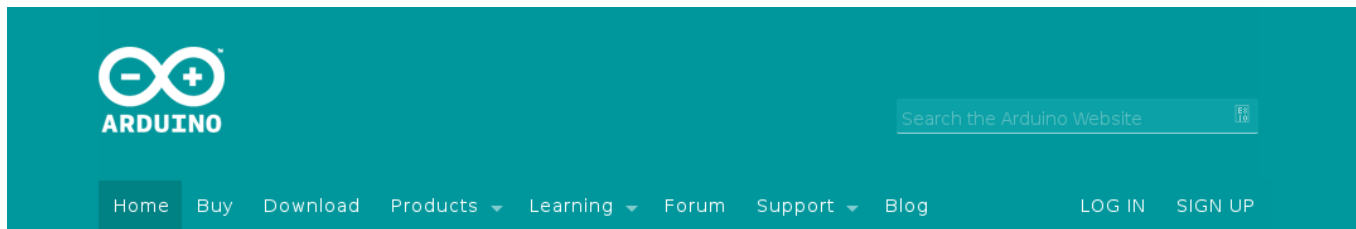
Editable source files for CAD software such as KiCad or EAGLE

✓ **Bill of Materials (*BoM*)**

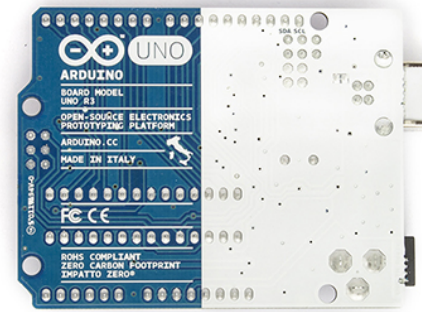
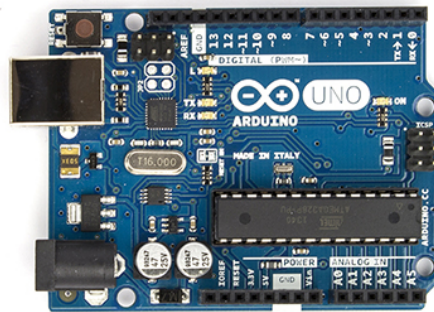
Best practice: all components available from distributors in **low quantity**

Open Source Hardware

Example: **Arduino** achieved **critical mass** by **sharing** their hardware designs and source code



Arduino Uno



Arduino: The Documentary describes the team's motivation



Open Source Hardware



- ✓ Example: [Arduino Uno](#) schematic and PCB layout design files for EAGLE CAD can be downloaded from [Arduino.cc](#)

The screenshot shows a web browser window with the URL <https://www.arduino.cc/en/Main/ArduinoBoardUno>. The page features a teal navigation bar with links: Buy, Software, Products, Learning, Forum, Support, and Blog. The main content area is titled "Documentation" and includes a sidebar with links: Overview, Get Inspired, Related Items, Technical Specs, and Documentation. The main text states: "OSH: Schematics, Reference Design, Board size" and "Arduino / Genuino Uno is open-source hardware! You can build your own board using the following files:". Below this text are two download buttons: a yellow button for "EAGLE FILES IN .ZIP" with a logo, and a brown button for "SCHEMATICS IN .PDF" with a schematic symbol.

Arduino - ArduinoBoa... x +

https://www.arduino.cc/en/Main/ArduinoBoardUno

Search

Buy Software Products Learning Forum Support Blog

Documentation

Overview

Get Inspired


Related Items


Technical Specs

Documentation

OSH: Schematics, Reference Design, Board size

Arduino / Genuino Uno is open-source hardware! You can build your own board using the following files:

 EAGLE FILES
IN .ZIP

 SCHEMATICS
IN .PDF



Open Source Hardware



Publish documentation with an
Open Source license:

- Creative Commons Share-Alike: **CC-BY-SA**
 - Non-Commercial (NC) clause is NOT acceptable
- Copyleft: **GPLv2, GPLv3**
- Permissive: **Apache, BSD, MIT**
- OSHW inspired: **CERN OHL, TAPR, SolderPad**



CERN Open Hardware Licence

- Originally written for **CERN** designs hosted in the **Open Hardware Repository**
- Can be used by **any designer** wishing to **share design** information using a **license compliant** with the **OSHW definition criteria**.
- **CERN OHL version 1.2**
Contains the license itself and a guide to its usage



CERN Open Hardware Licence

Myriam Ayass, legal adviser at CERN and author of the CERN OHL:

- **OHL** is to hardware what **GPL** is to software
- Similar principles to Free or Open Source software
- Anyone should be able to:
see the source*, **study it**, **modify it** and **share it**

**the design documentation in case of hardware*



CERN Open Hardware Licence



- Video interview with [Javier Serrano](#)
- physicist and electronics engineer at CERN
- co-author of the **CERN Open Hardware License**
- creator of the **Open Hardware Repository**



Open Source Hardware



**Licenses, Copyright and Patents
can get confusing!**

Review of Popular OSHW Licenses

Video of Ari Douglas at OHS 2014



Open Source Hardware

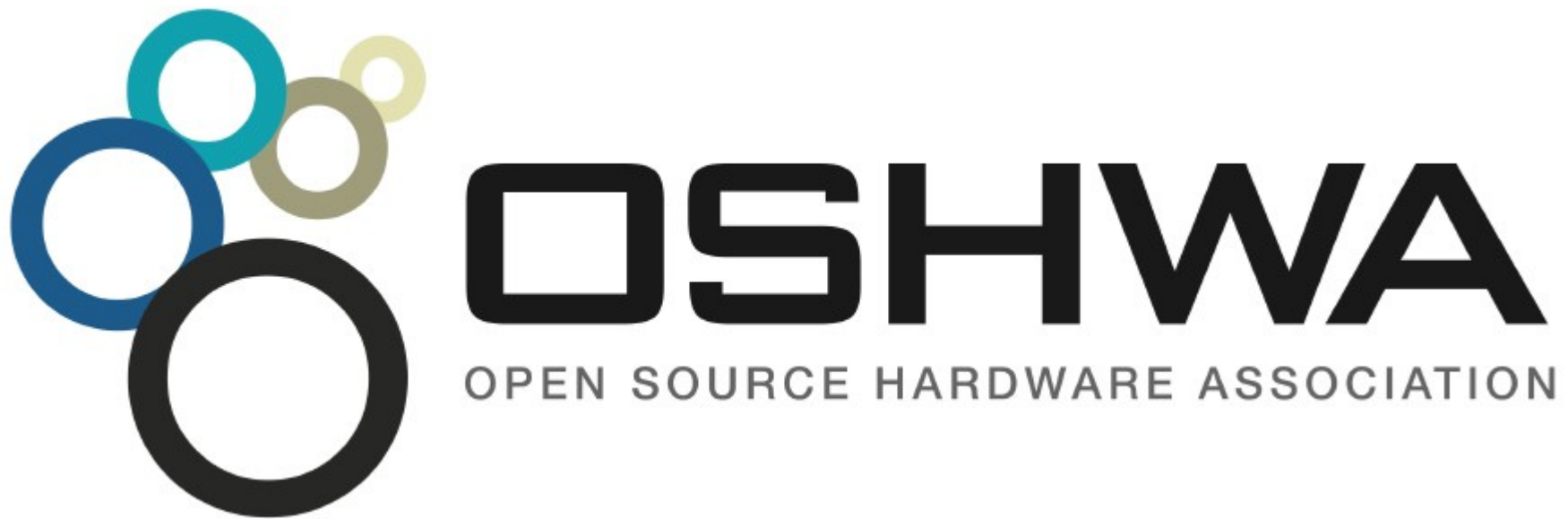


What is the spirit of Open Source?

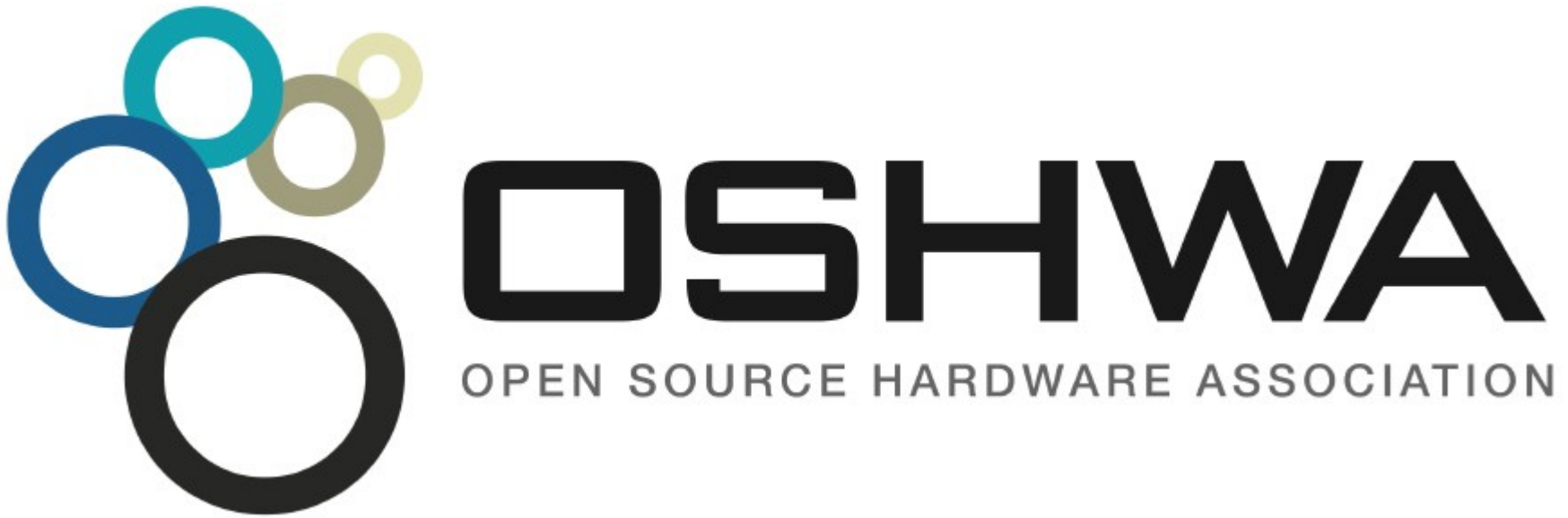
- Publish everything that will:

enable collaborative development

- Goal is NOT to check a box on a marketing brochure or add keywords to a crowdfunding campaign



- US-based *501(c)3* non-profit organization
- Hosts the [Open Source Hardware definition](#)
- “aims to be the **voice of the open hardware community**, ensuring that technological knowledge is accessible to everyone, and encouraging the collaborative development of technology”



- OSHW Best Practices
- Quick Reference Guide
- OSHW "May and Must" (PDF)
- OSHW Checklist (PDF)

Open Hardware Summit (OHS)

- **OHS 2018:** MIT, Thursday, September 27th
(Cambridge, MA, USA)
- *7 prior summits:*
 - **2010, 2011:** New York Hall of Science
 - **2012:** Eyebeam (*NYC*)
 - **2013:** MIT (*Boston area*)
 - **2014:** Roma, Italia!
 - **2015:** Philadelphia, USA
 - **2016:** Portland, Oregon, USA
 - **2017:** Denver, USA

Open Hardware Summit (OHS)

- OHS 2017: Engineering Open Source Hardware**



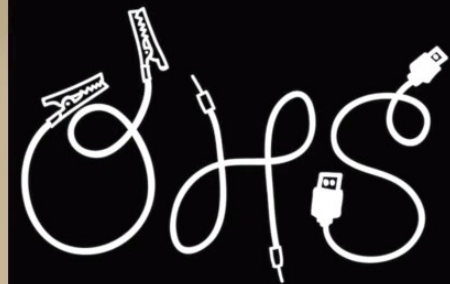
Panel: Engineering Open Source

Michael Ossman
Great Scott Gadgets

Toni Klopfenstein
Sparkfun Electronics

Ben Malouf
Aleph Objects Inc.

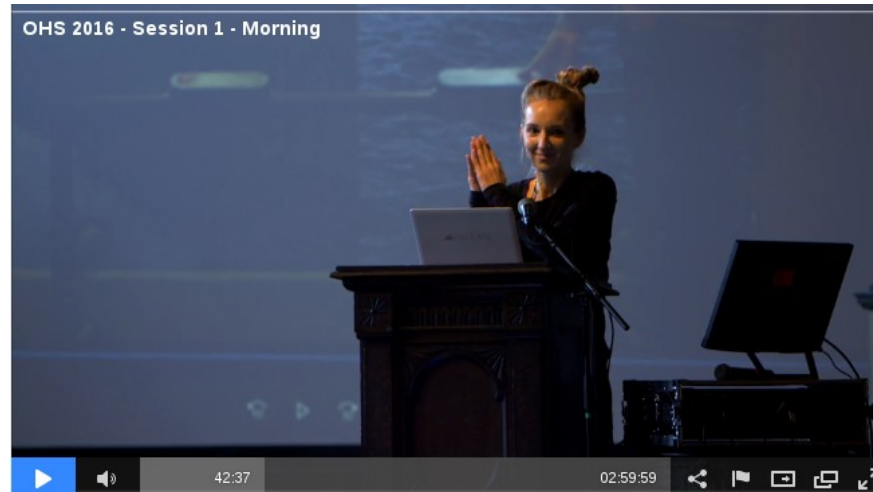
Katherine Scott
OSHW Board
OHS Committee



open source
hardware

Open Hardware Summit (OHS)

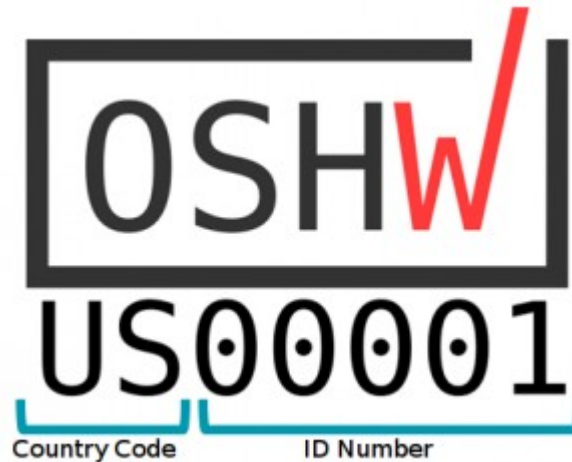
- OHS 2016 morning sessions



- OHS 2016 afternoon sessions



Open Source Hardware Certification Program



- Allows hardware that complies with the community definition of Open Source Hardware to display a certified OSHw logo
- Make it easier for users of OSHw to track down documentation and information
- *More information:* certificate.oshwa.org

Open Hardware Europe Summit 2016



- [Video playlist on YouTube](#)
- [Open Hardware Europe Summit](#)
 - “The global open hardware community met in Vienna, Austria to give talks about new aspects, new methods and lessons learned for the open hardware movement.”

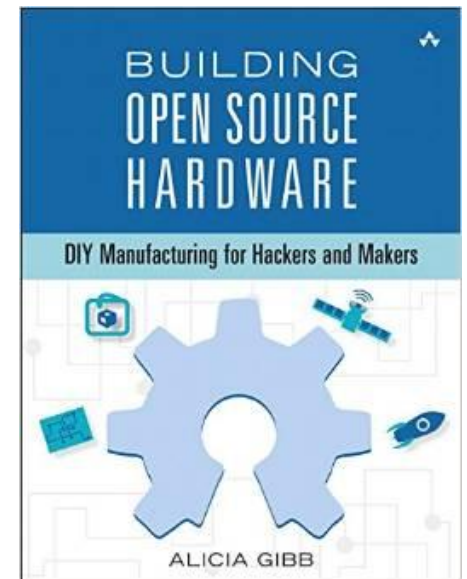


Open Source Hardware



Resources

- Join OSHWA
- Subscribe to the mailing list
- Post in the OSHWA Forum
- Follow on Twitter:
 - @OHSummit
 - @oshwassociation
- Building Open Source Hardware
by Alicia Gibb (*executive director of OSHWA*)



Slides: <https://github.com/pdp7/talks/blob/master/oshw-bof-lfelc-pdx-2018.pdf>



Section:
OSHW in Science

Suggestions from the OSHWA mailing list

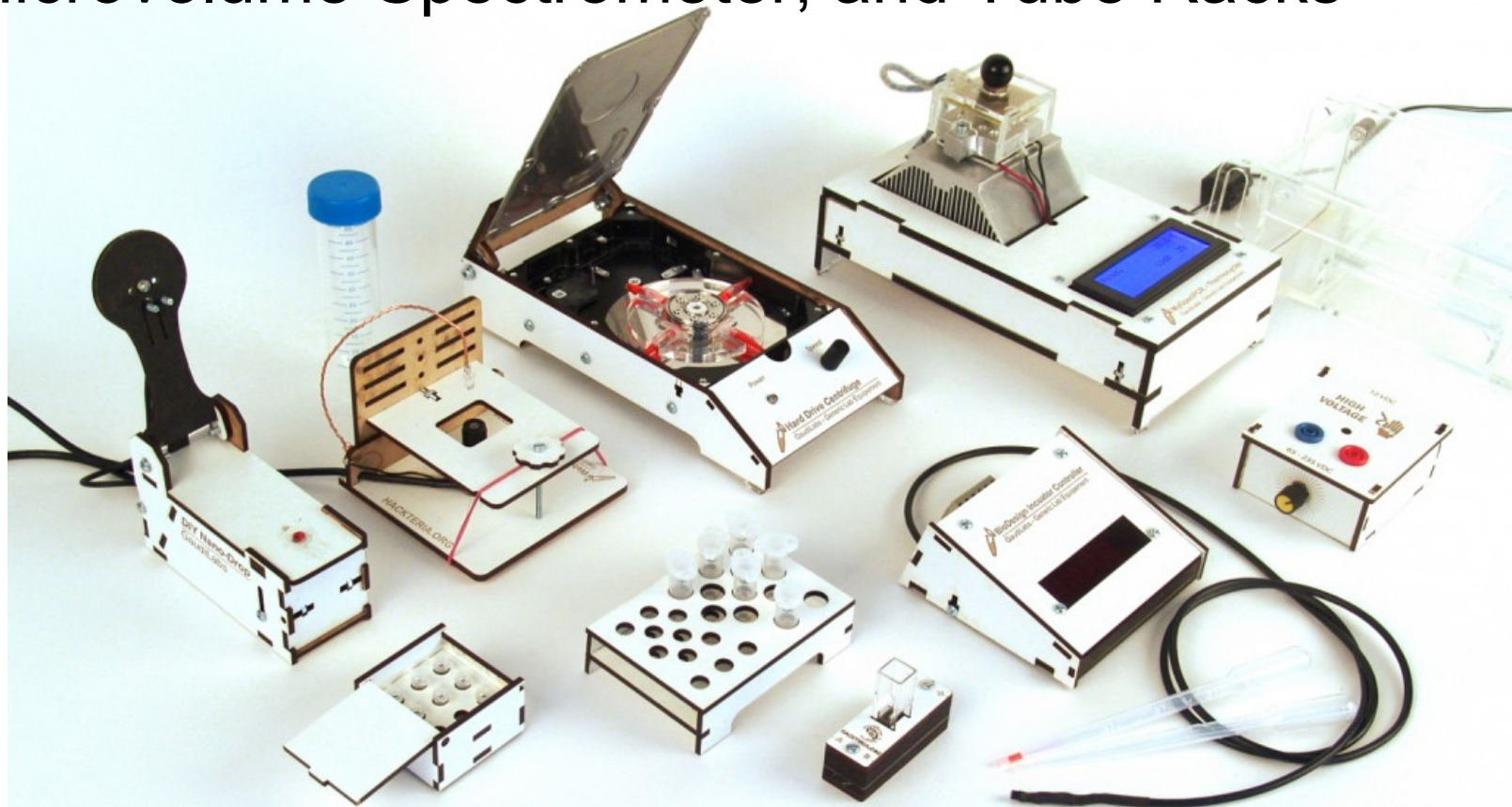
Public Lab

- “Using inexpensive DIY techniques, we seek to change how people see the world in environmental, social, and political terms.”
- Riffle: Open Source Water Monitoring
- Desktop Spectrometry
- Balloon Mapping Kit



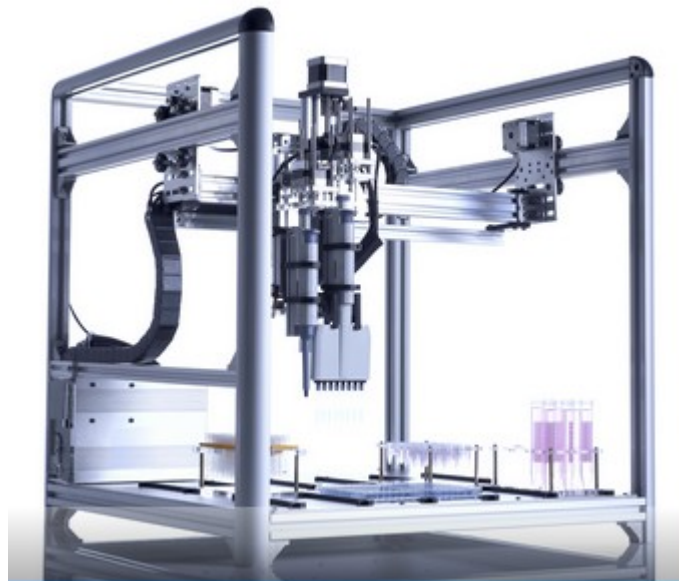
Generic Lab Equipment

- GaudiLabs in Switzerland has designed: WebCam Microscope, Hard Drive Centrifuge, Incubator Controller, Gel Box and HV Supply, Turbidity Meter, Microvolume Spectrometer, and Tube Racks



OpenTrons

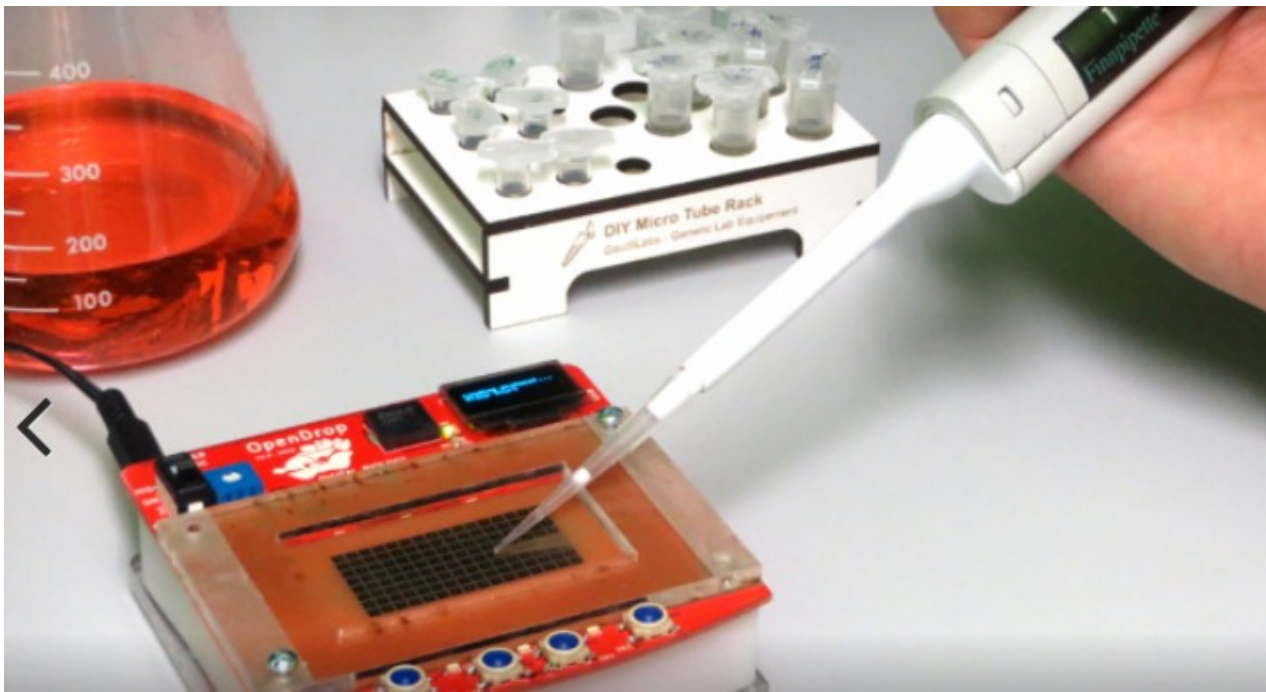
- **Robots for Biologists**
- “We think biologists should have robots to do **pipetting** for them.”
- “They should be able to spend their time designing experiments and analyzing data.”



OpenDrop



- “Desktop Digital Biology Laboratory”
- digital **microfluidics** platform for research
- aim of making personal lab-automation accessible to more people



OpenPCR

- **PCR** is a method of **copying DNA molecules**.
- **OpenPCR** is a project to develop open source hardware, software, and protocols to perform **PCR** and **Real-Time PCR reactions**



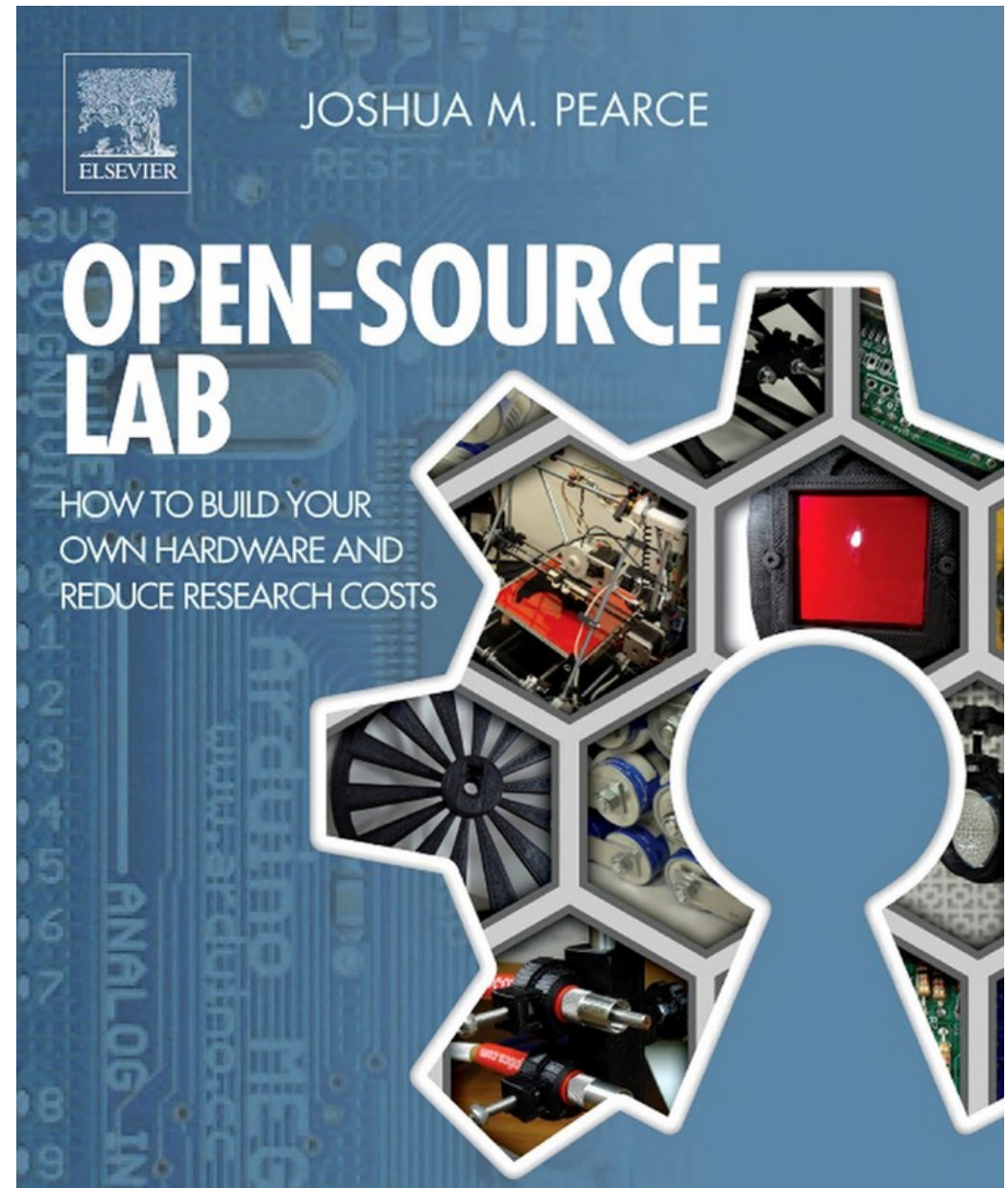
Open Source Imaging Initiative

- “development of **medical imaging devices**, aiming to make health-care benefits of modern instruments **accessible to many more**”
- “**pool the knowledge and experience** of many experts in open-source designs for **MRI**”
- Opencore NMR is an open-source toolkit for implementing an NMR spectrometer



Open-Source Lab

- “open-source 3D printing and microcontrollers running on free software enables scientists, engineers, and lab personnel in every discipline to **develop powerful research tools at unprecedented low costs**”
- Author **Joshua Pearce** runs the **MOST research group** which is exploring the way solar photovoltaic technology can sustainably power our society



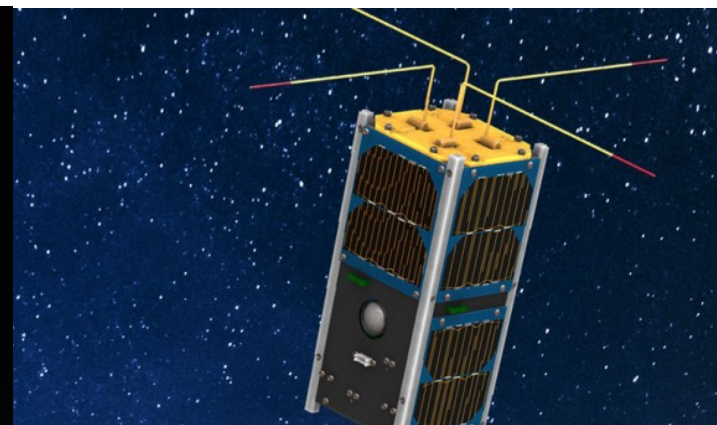
Gathering for Open Science Hardware

- “**GOSH** is a diverse, global community working to enhance the sharing of open, scientific technologies”
- [Video of GOSH 2016 at CERN](#)
- [GOSH 2016 in the Journal of Open Hardware](#)
- [GOSH 2018](#): Shenzhen, China



Libre Space Foundation

- Non-profit for Open Source HW & SW in Space
- **SatNOGS**: global network of satellite ground stations designed as an open source participatory project
- **UPSat**: 1st open source hardware & software satellite
 - Launched in 2017
 - **"Flying The First Open Source Satellite"**





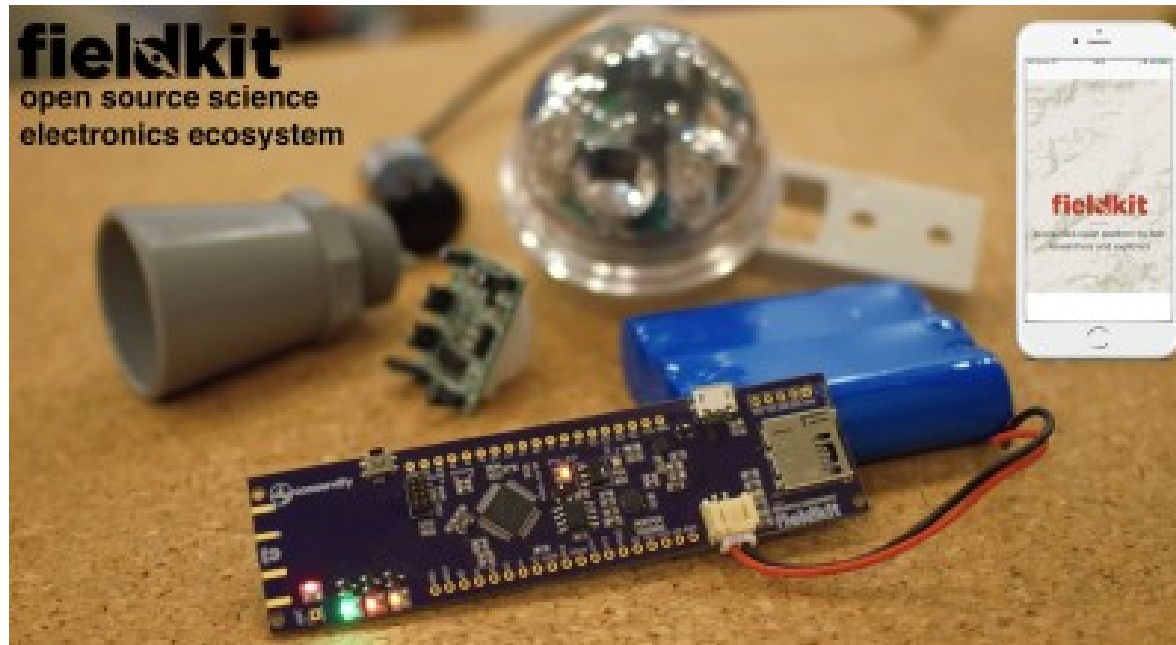
- building and deploying hardware to help monitor ecological problems in the wildest places on on Earth
 - sensors to monitor ocean fishing practices
 - watch the movements of glaciers
 - gather real time data about Okavango Delta in Botswana.
- Shah Selbe of Conservify at Hackaday Supercon:

Wild Hardware: Adventures with Ecological IoT and National Geographic



fieldkit

- “brought thousands of people along with us into the Okavango Delta on a ‘live data’ expedition”
- “tools to collect and share field-based research data and to tell stories through interactive visualizations for conservation, science, exploration and education”

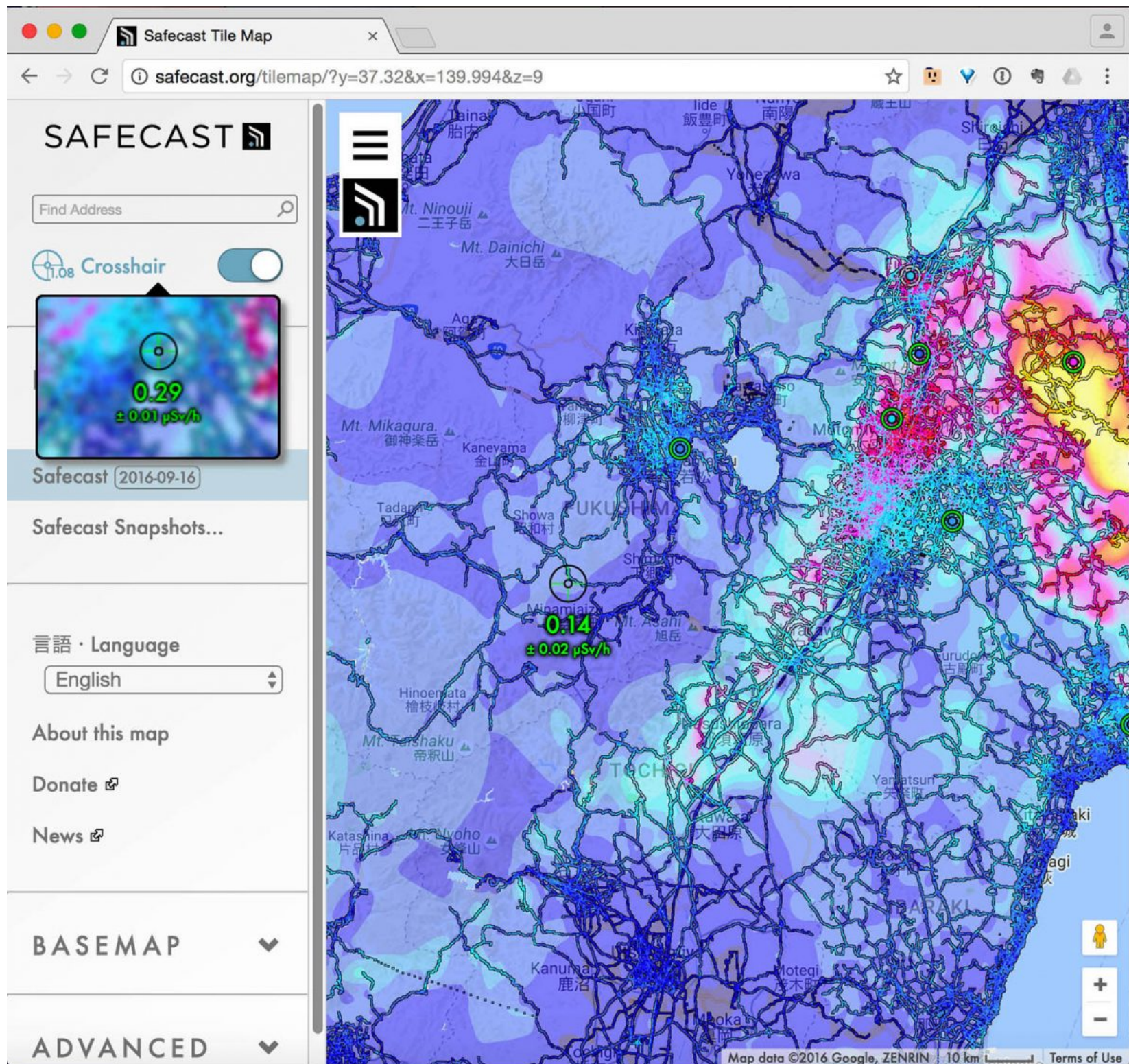


Safecast

- international organization devoted to open citizen science for the environment
- created after the Fukushima Daiichi nuclear disaster in Japan, because accurate and trustworthy radiation information was not available to the public



SAFECAST



Safecast bGeigie Nano

- mobile, GPS enabled, logging, radiation sensor
- designed for mounting on the outside of a car window but can be used on bicycles, trains, planes, and other modes of transportation



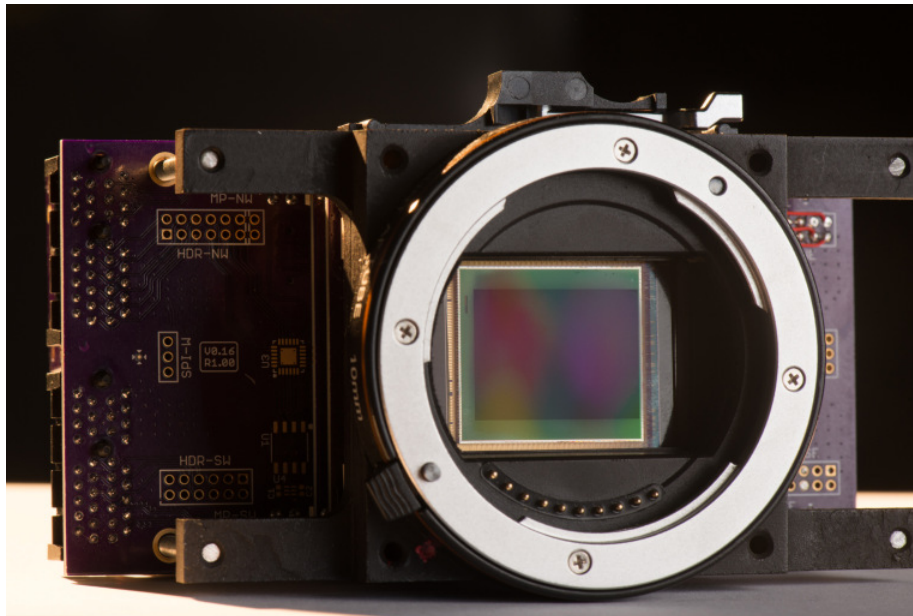
Slides: <https://github.com/pdp7/talks/blob/master/oshw-bof-lfelc-pdx-2018.pdf>



Section:
OSHW PRODUCTS



- “The goal of the global community-driven apertus° project is to create a variety of powerful, affordable, free (in terms of liberty), **sustainable and open digital cinema tools** that we as **filmmakers love to use**”





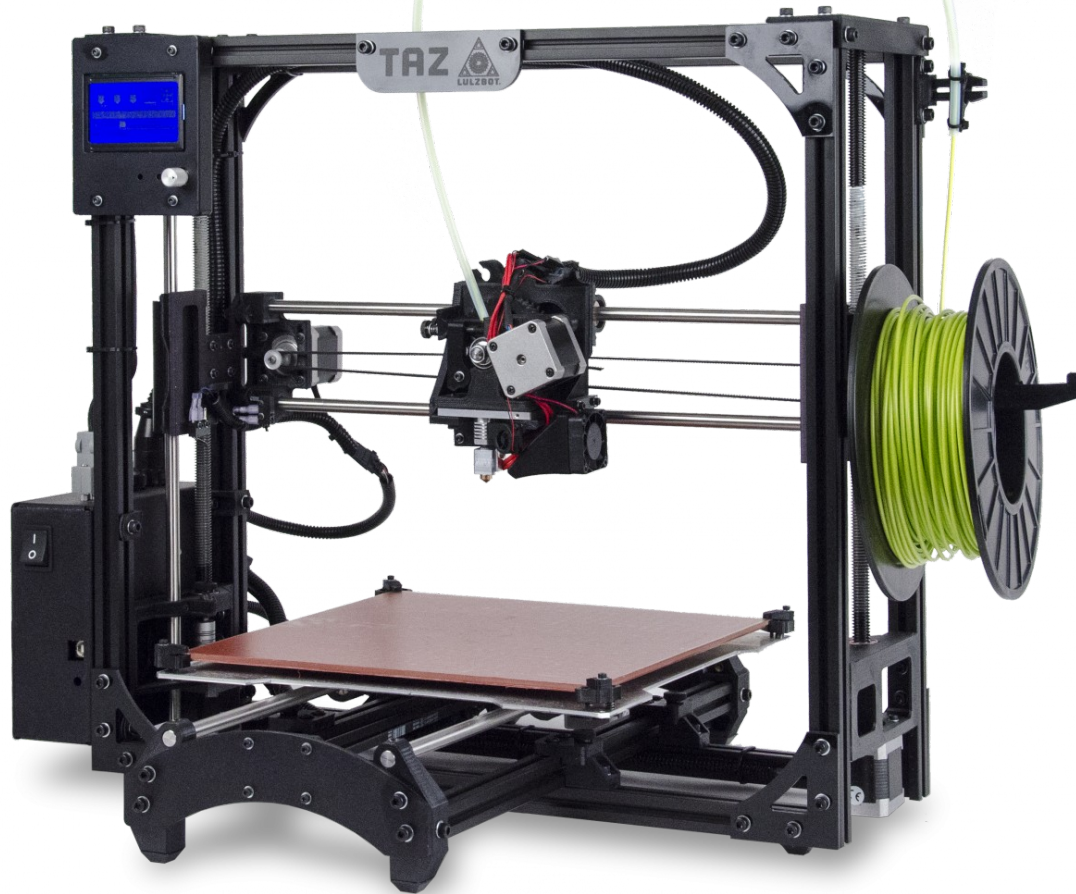
- “**AXIOM product line** is the result of this ongoing endeavor and after **successful crowd funding** and receiving an **EU Innovation grant** is well on track to redefine the industry well beyond the DIY garages and hobbyist labs”

AXIOM
Beta



Lulzbot 3-D Printers

- 100% Open Source Hardware & Software



FSF Respects Your Freedom certified!



RepRap 3-D Printers



- RepRap started as an academic initiative to develop a **low-cost 3D printer** that can **print most of its own components**
- Giving Manufacturing a New Life by Adrian Bowyer
- Prusa i3 M2 RepRap named Make:'s Best 3D Printer for 2017



Novena laptop

- Created by Bunnie Huang & Sean Cross (xobs)
 - Chumby, “Hacking the Xbox”, [amazing reverse engineers](#)
- 100% Open Source Hardware laptop
- Quad-core 1.2GHz ARM, 4GB RAM, SSD, WiFi
- Xilinx FPGA for custom hardware design
- Software Defined Radio (SDR) module





Section:
LINUX on OSHW

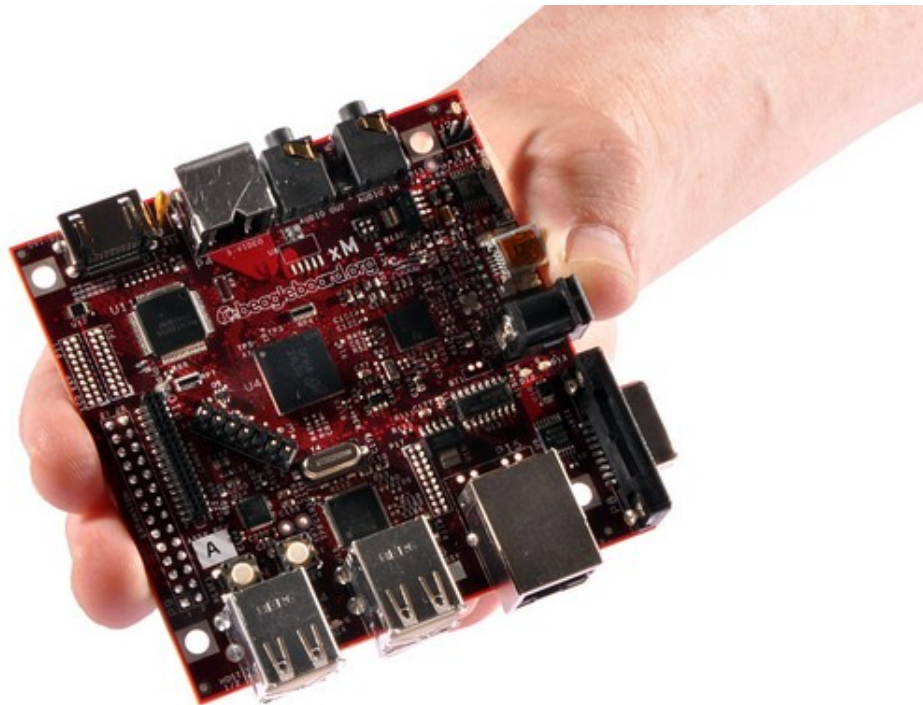


- Open Source Hardware computing for Makers, Educators & Professionals
- Developed by BeagleBoard.org Foundation and BeagleBoard.org Community
- Manufacturers: element14, GHI, Seeed



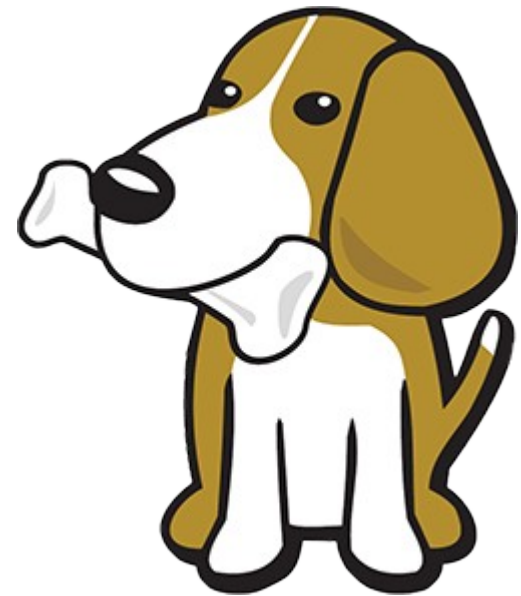


BeagleBoard.org released the first **BeagleBoard**, an affordable, open hardware ARM computer in **2008**





Maker focused, Altoids tin sized
BeagleBone introduced in **2011**





More affordable, more powerful
BeagleBone Black in 2013





Open Source Hardware BeagleBone derivatives

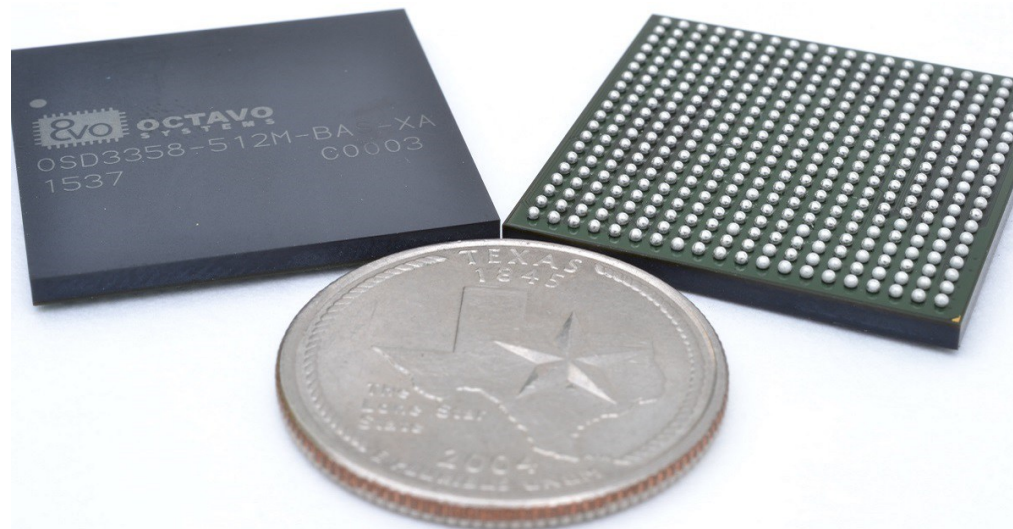
	Capes	HDMI	Flash	Special
BeagleBoard.org BeagleBone	Y	N	N	JTAG
BeagleBoard.org BeagleBone Black	Y	Y	Y	-
Arrow BeagleBone Black Industrial	Y	Y	Y	Industrial
Element14 BeagleBone Black Industrial	Y	Y	Y	Industrial
SeeedStudio BeagleBone Green	Y	N	Y	Grove
SanCloud BeagleBone Enhanced	Y	Y	Y	1GB, 1Gbit, wireless
BeagleBoard.org BeagleBone Blue	N	N	Y	Robotics
BeagleBoard.org BeagleBoard-X15	N	Y	N	Big jump in CPUs and I/O



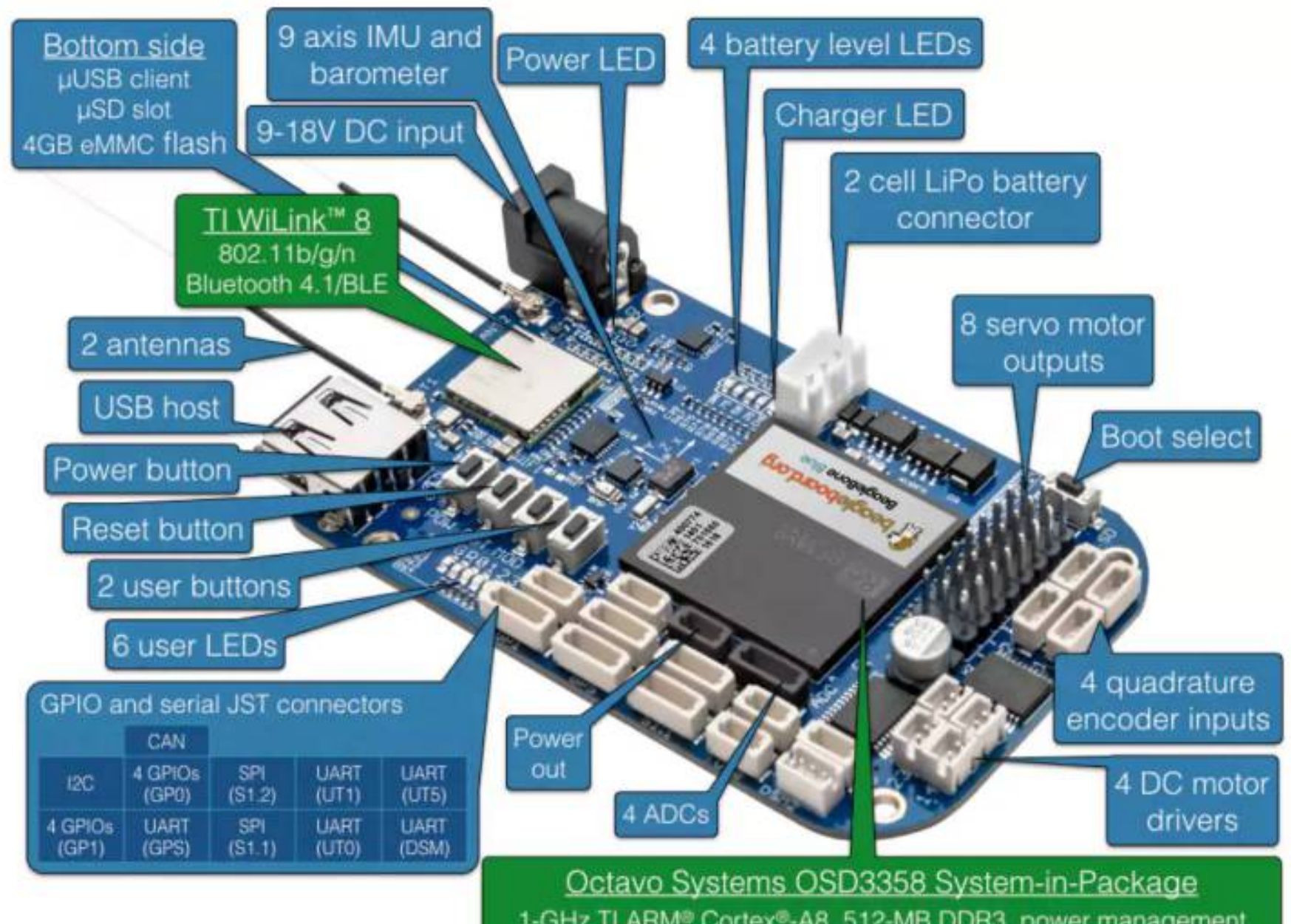
BeagleBone Black Wireless



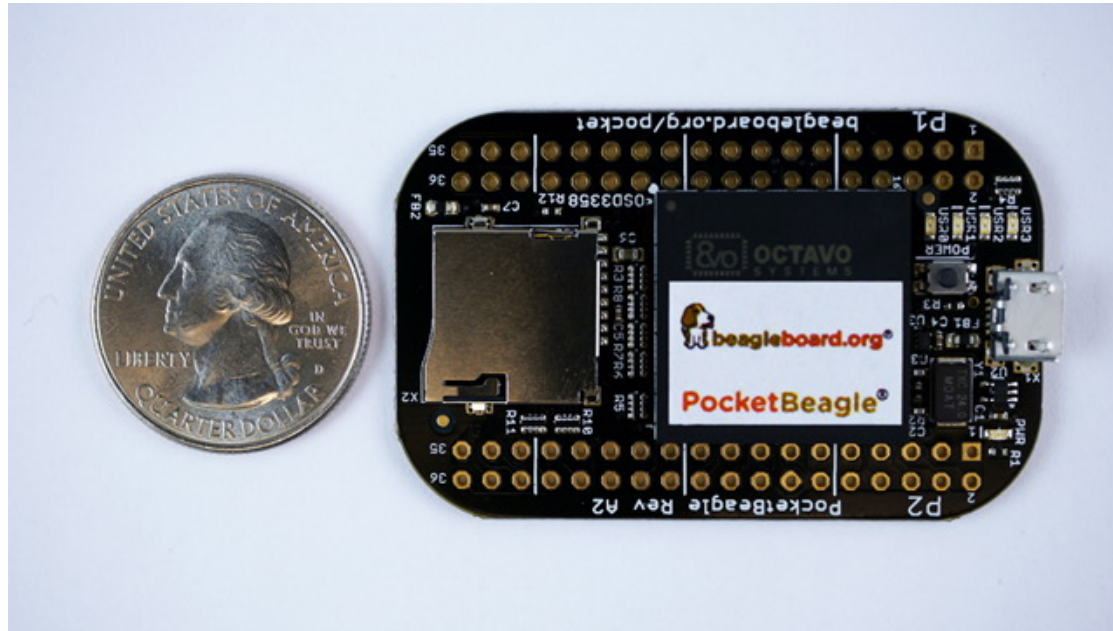
- CadSoft EAGLE design files hosted on GitHub
- Bill of Materials: every part available in qty 1
- Octavo System-in-Package (SiP) packages several ICs (*CPU, RAM, etc*) into one large-pitch BGA chip to simplify PCB layout and assembly



BeagleBone Blue: complete Linux robotics controller. 4 layer PCB designed in EAGLE.



BeagleBoard.org PocketBeagle



- Michael Welling designed the “*PocketBone*” using the Octavo SiP and shared on Hackaday.io
- In response to online demand, BeagleBoard.org worked with GHI in Michigan to design and manufacture a new product: the PocketBeagle

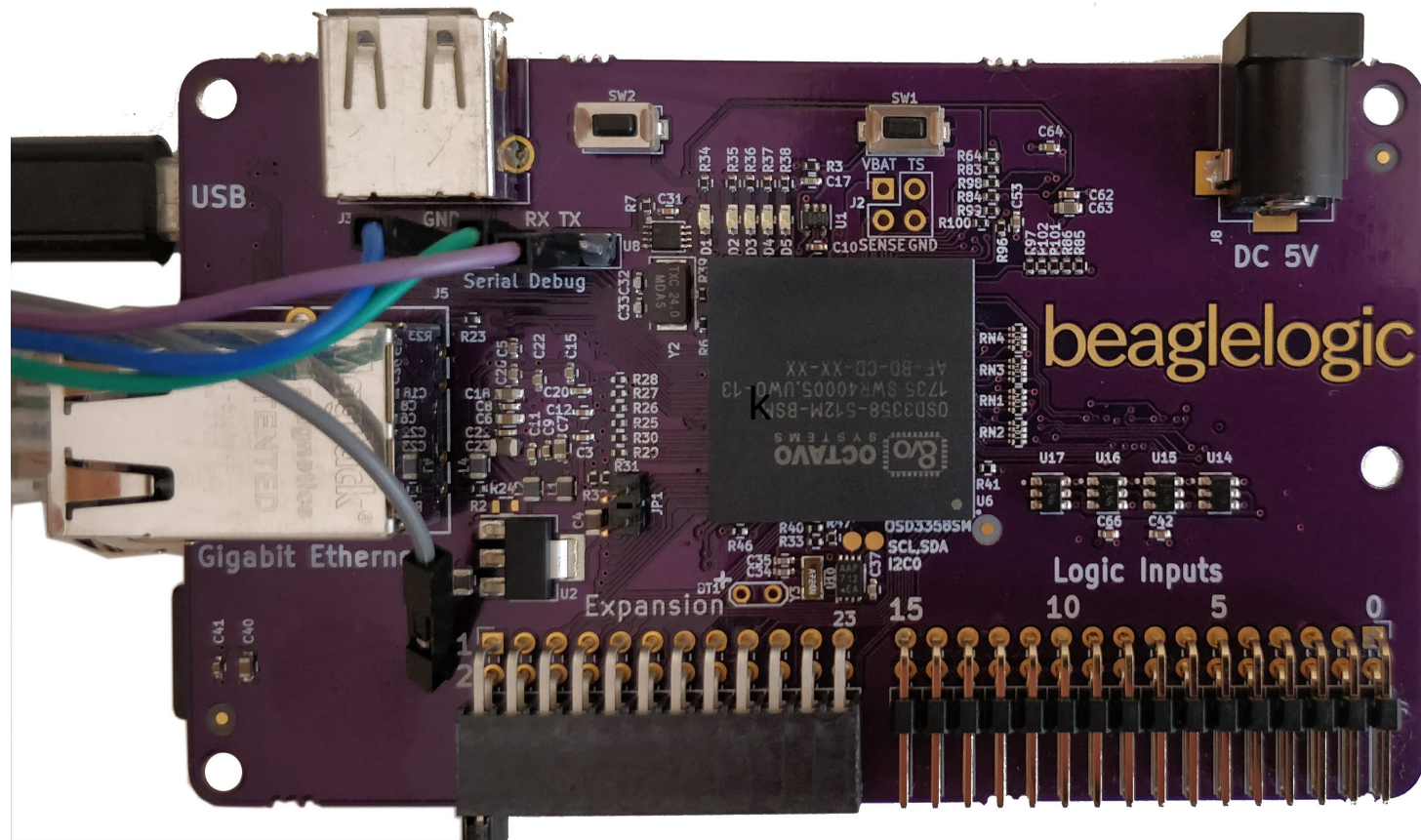
BeagleBoard.org PocketBeagle

- PocketBeagle design makes it feasible for individuals to create their own derivatives
- 4 layer PCB published for EAGLE and KiCad
- Low cost assembly is possible with solder paste stencil and toaster oven



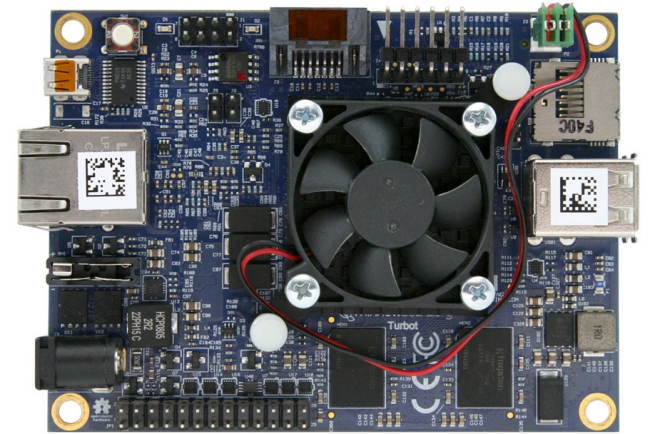
BeagleLogic

- Kumar Abhishek created a derivative board intended to be used as a logic analyzer
- Finalist in the Best Product round of the Hackaday Prize





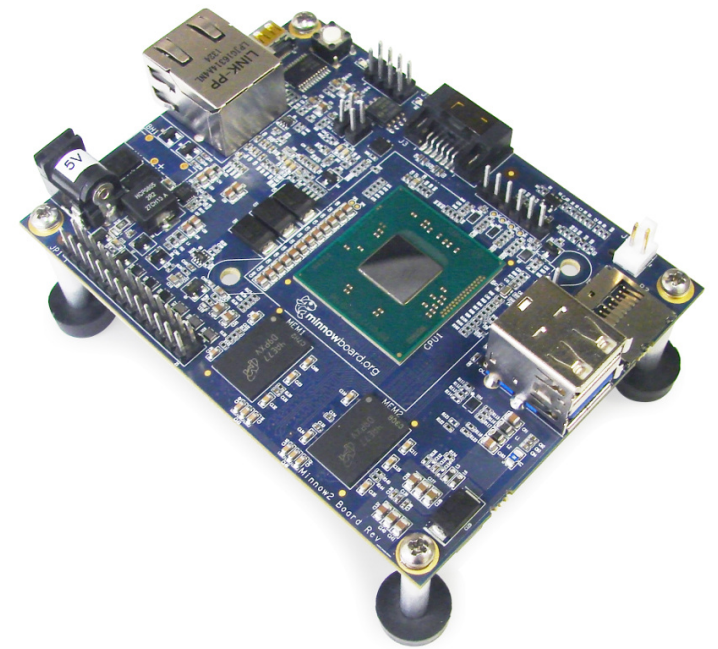
MinnowBoard



- 64-bit Intel Atom (dual or quad core)
- **MinnowBoard Turbo**
- USB 3.0, SATA, PCIe, Gigabit Ethernet, HDMI
- Integrated Intel HD Graphics
 - Open Source Mainline Linux drivers!



MinnowBoard



- Manufactured by [ADI](#)
- Released under Creative Commons **CC-BY-SA**
- [Download design files:](#)
 - ✓ Schematic
 - ✓ Board Layout
 - ✓ Bill of Materials



OLinuXino



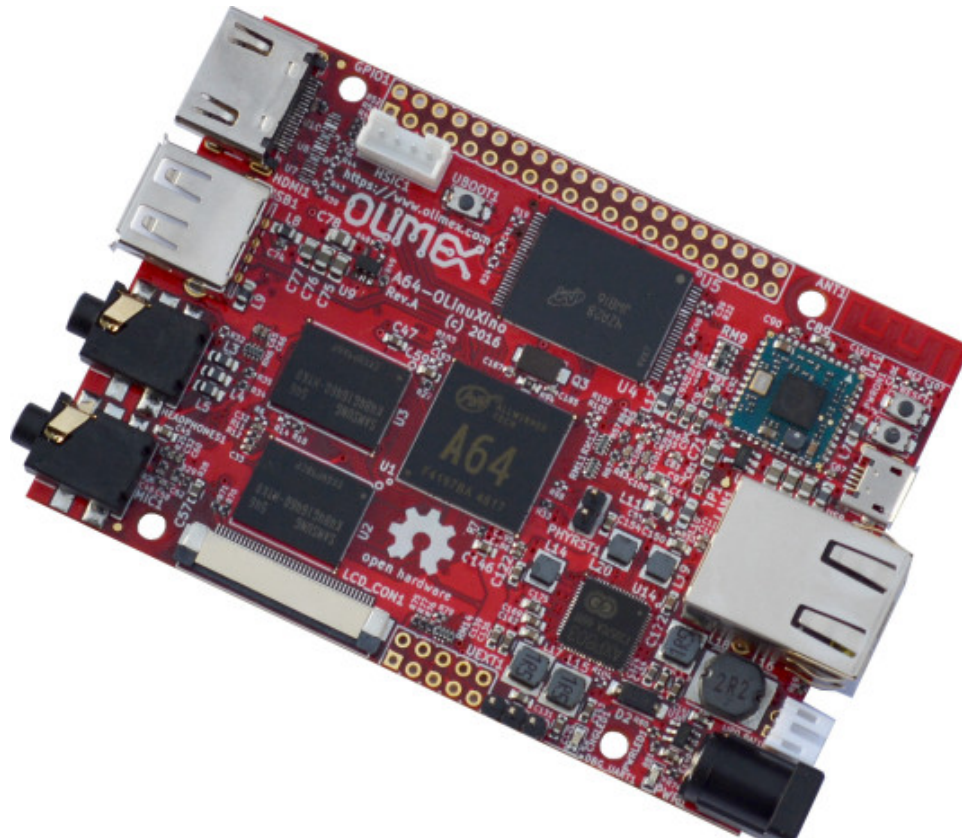
- Low cost OSHW Linux computers
- Designed and manufactured by **Olimex** in **Bulgaria**
- Great blog post:
[Open Source Hardware, why it matters and what is pseudo OSHW](#)



A64-OlinuXino



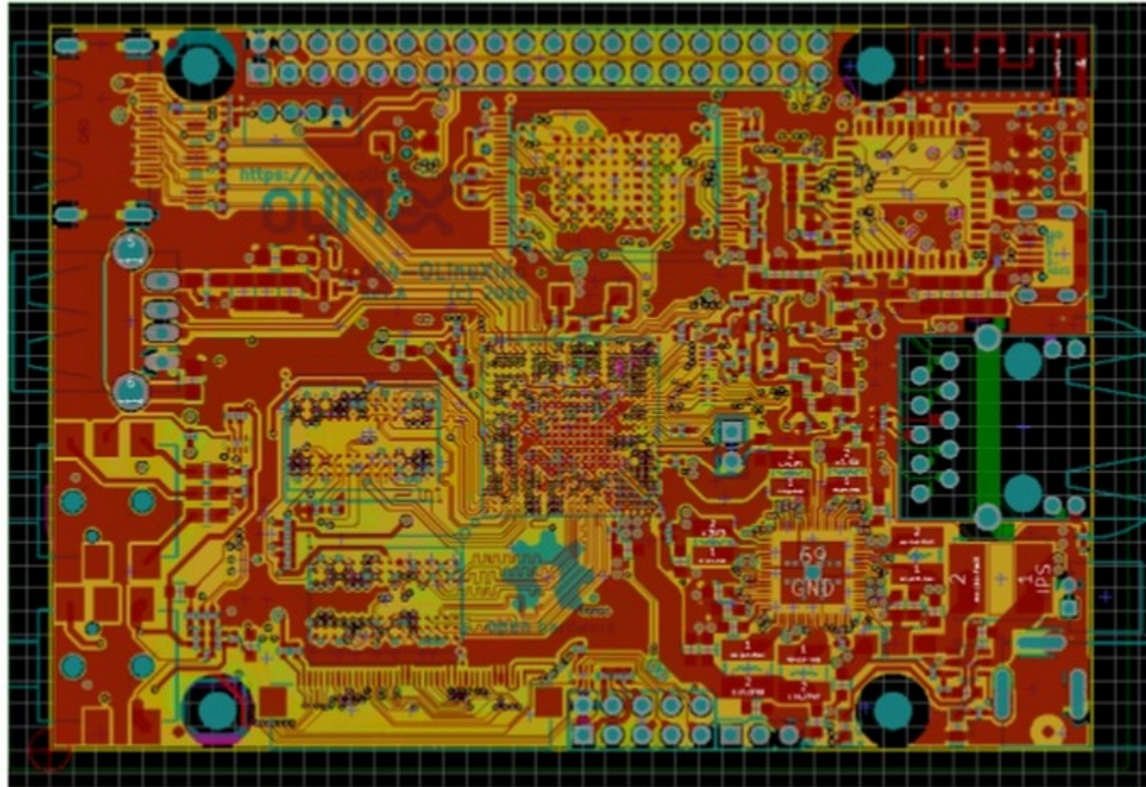
- Allwinner A64: Quad Core **64-bit ARM**
- Designed with Open Source **KiCad**
- 1GB RAM, 4GB eMMC, WiFi+BLE4.0





Using FOSS tools for OSHW project

Designing with KiCAD of 64-bit ARM board



Tsvetan Usunov, OLIMEX Ltd

FOSDEM 2016

[Slides](#) / [Video](#)

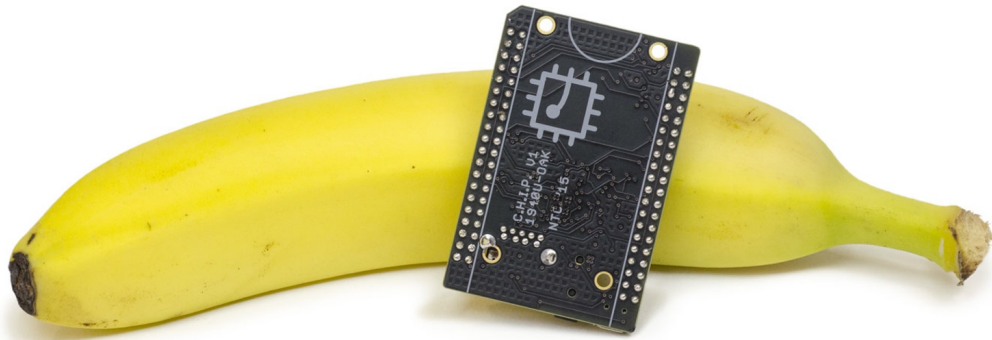


- **KiCad** is an Open Source EDA suite including Schematic Capture and PCB Layout
- Cross platform: **Windows, Mac OS and Linux**
- **CERN has contributed** professional CAD features for high-speed digital design
- Learn to design your own PCB in KiCad with:
Getting to Blinky

- “DIY Open Source Hardware Software Hacker's friendly Modular Laptop”
- Developing an Open Source Laptop talk by Olimex founder Tsvetan Usunov at Hackaday Belgrade
- Design files on GitHub:
“everyone can download & learn, study, edit, modify”



CHIP

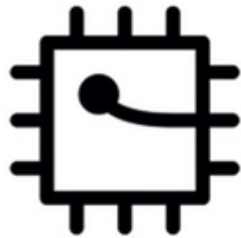


The World's First \$9 Computer

- getchip.com
- Next Thing Co. in Oakland
- Kickstarter in 2015
- *March 2018: not in stock?*

"C.H.I.P., PocketCHIP & Voder's Maker Next Thing Co. Is Still Up and Running (Correction)"

C.H.I.P. is OSHW



- **GitHub:** [NextThingCo/CHIP-Hardware](#)
 - Schematics
 - PCB Layout
 - Bill of Materials (*BoM*)
- **License:**
 - Creative Commons Attribution-ShareAlike (*CC-BY-SA*)

EOMA68 Computing Devices

- Embedded Open Modular Architecture
- “responsible about both the ecological and the financial resources required to design, manufacture, acquire and maintain our personal computing devices.”
- “**This campaign** therefore introduces the world’s first devices built around the EOMA68 standard, a freely-accessible royalty-free, unencumbered hardware standard”
- Estimated to ship in 2018



**Are there other OSHW boards
that run Linux?**

Please let me know!

drew@pdp7.com Twitter: @pdp7

Create a list on eLinux wiki?

Any OSHW on 96boards.org?



[About](#) [Products](#) [Projects](#) [Documentation](#) [Blog](#) [Forums](#) [Q](#)

Consumer Edition (CE)

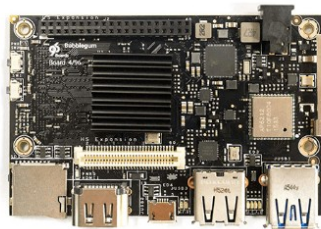
[96Boards](#) » [Products](#) » [Consumer Edition \(CE\)](#)

[Latest Boards](#) [Consumer Edition](#) [Enterprise Edition](#) [IoT Edition](#) [Mezzanine Products](#) [Accessories](#)

The 96Boards Consumer Edition (CE) specification targets the mobile, embedded and digital home segments. The boards below are all certified conforming to this specification, which defines a fixed set and location

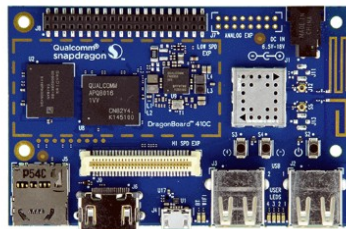


[Specification](#)



bubblegum-96

Board based on Actions Semi S900 Processor...



DragonBoard™ 410c (Arrow)

Board based on Qualcomm® Snapdragon™ 410 processor...



Hikey (LeMaker)

Board based on HiSilicon Kirin 6220 processor...



HiKey 960

Board based on Huawei Kirin 960 octa-core ARM® big...

[Read More](#)

[Buy](#)

[Read More](#)

[Buy](#)

[Read More](#)

[Buy](#)

[Read More](#)

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Udoo: no PCB design files?

[START](#)[DISCOVER](#)[COMMUNITY](#)[RESOURCES](#)[PROJECTS](#)[DISTRIBUTORS](#)[SHOP](#)

DOCUMENTATION

DOCUMENTS

[USER MANUAL](#)

MECHANICAL SPECS

[3D MODEL](#)

SCHEMATICS














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[SCHEMATICS](#)[TOP](#)[BOT](#)

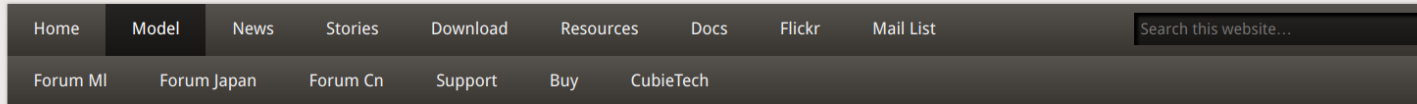
OTHER FILES

[DATASHEET](#)[BOM](#)

Radxa: no PCB design files?

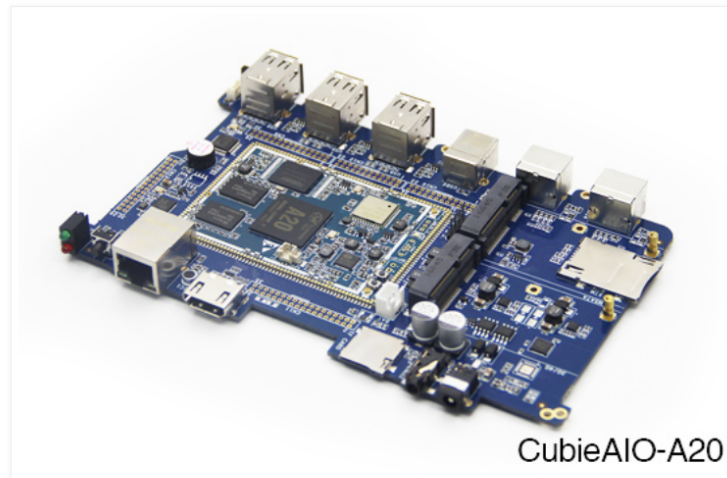
Home News Rock Rock2 Store Distributors Talk Contact About		
Name	Last modified	Size
 Parent Directory		-
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 componets_position_ref_top_20131025.pdf	21-Dec-2013 04:47	54K
 GPIO.xlsx	08-Oct-2014 10:38	14K
 RADXA_ROCK_20130903.dxf	05-Sep-2013 16:17	1.5M
 RADXA_ROCK_20131025.dxf	21-Dec-2013 04:51	794K
 RADXA_ROCK_PRO_20140610.dxf	19-Sep-2014 06:33	3.5M
 RADXA_ROCK_PRO_components_position_ref_20140610.pdf	19-Sep-2014 06:22	184K
 RADXA_ROCK_PRO_schematic_20140718.pdf	21-Jul-2014 02:04	462K
 RADXA_ROCK_schematic_20130903.pdf	05-Sep-2013 15:46	413K
 RADXA_ROCK_schematic_20131025.pdf	21-Dec-2013 04:51	415K
		Radxa Download

CubieBoard: no PCB design files?



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Model



Slides: <https://github.com/pdp7/talks/blob/master/oshw-bof-lfelc-pdx-2018.pdf>



Section:
Open Source and Libre Silicon

What about silicon?



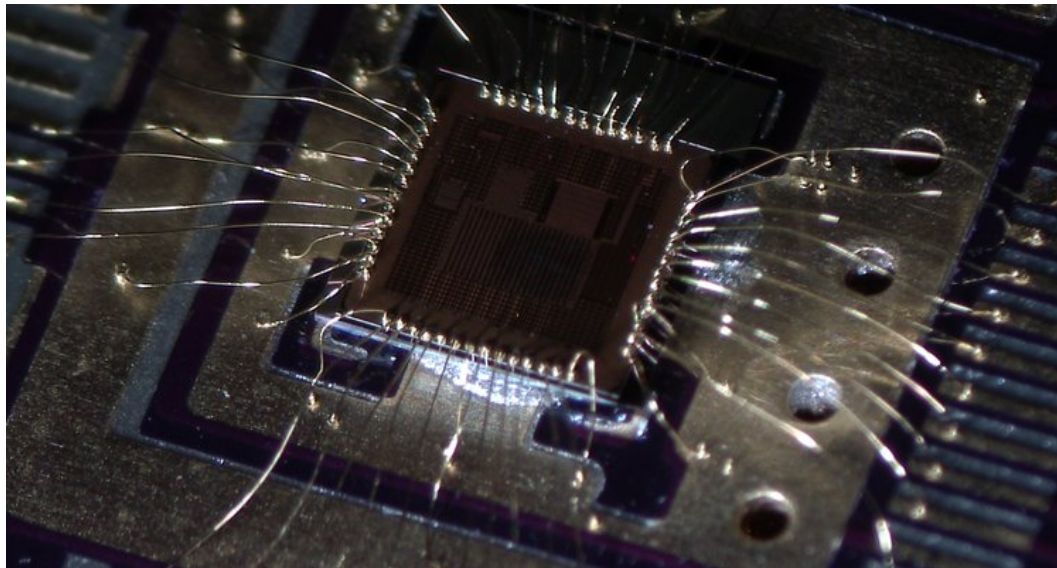
- **RISC-V: Free and Open RISC Instruction Set Arch**
 - “new instruction set architecture (ISA) that was originally designed to support computer architecture research and education and is now set to become a standard open architecture for industry”
 - Video: [Instruction Sets Want To Be Free: A Case for RISC-V](#)
 - Video: [Krste Asanovic presents](#) at RISC-V and Open Source Silicon Event in Munich on March 23, 2017

What about silicon?



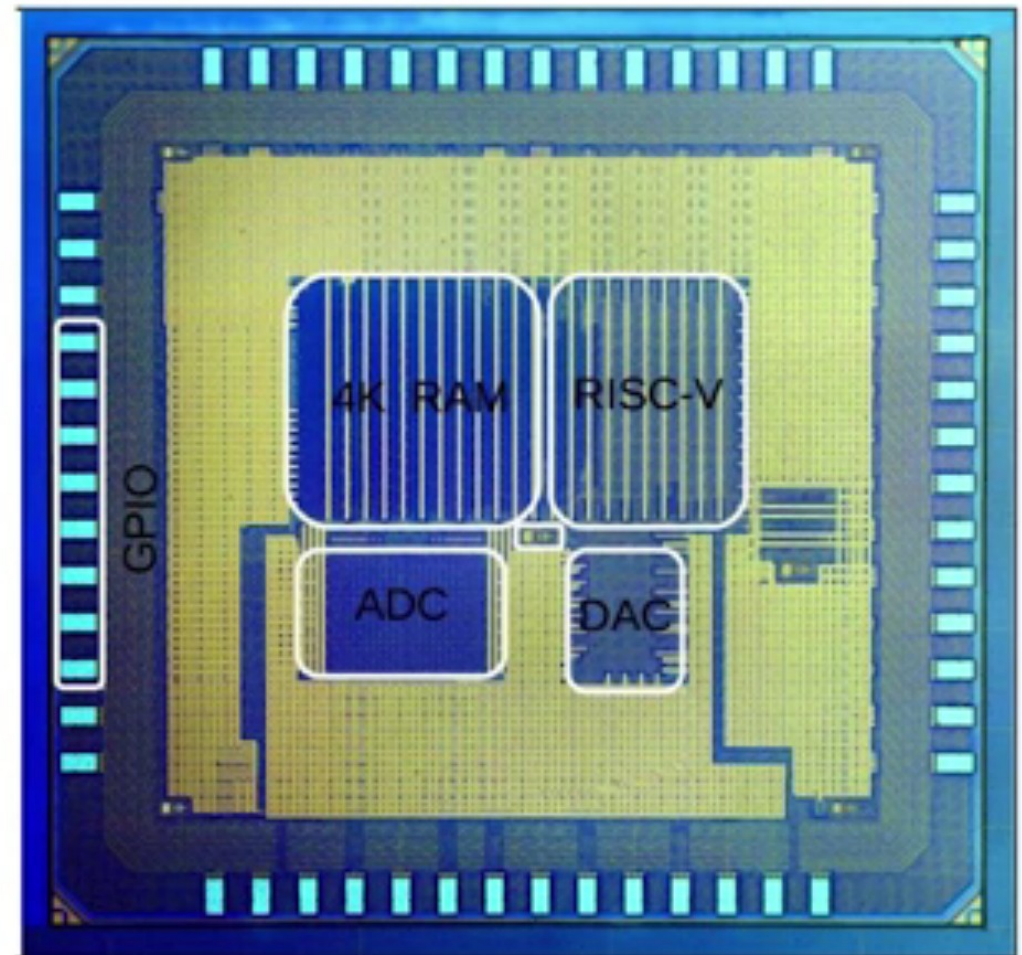
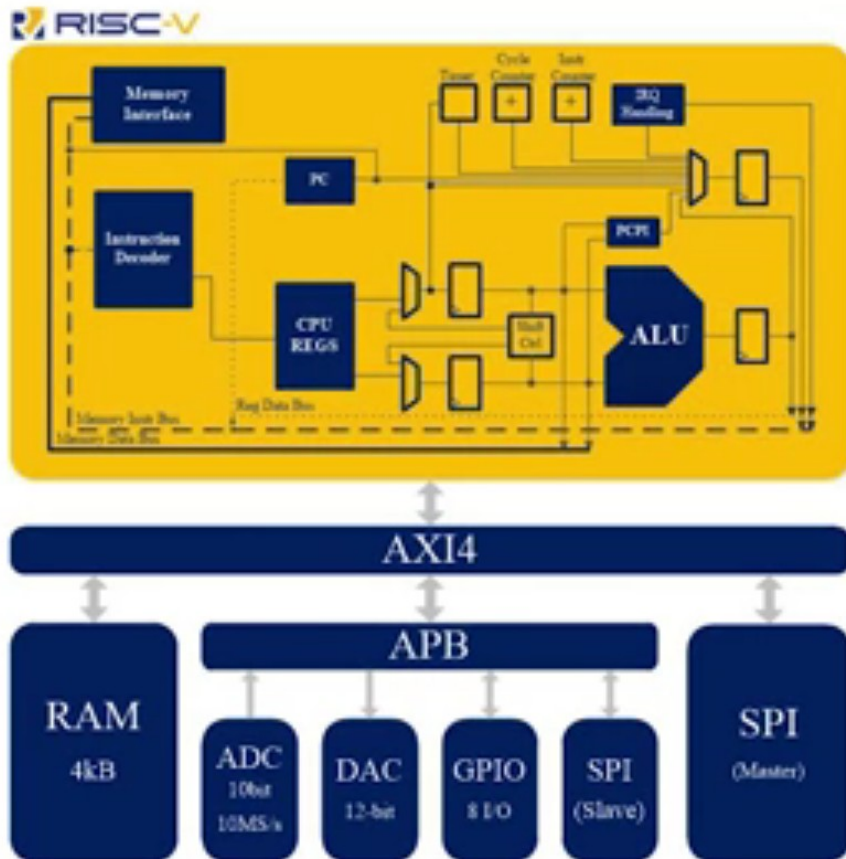
- OnChip Open-V

“completely free (as in freedom) and open source 32-bit microcontroller based on the RISC-V architecture”



What about silicon?

A 32-bit RISC-V based Microcontroller



What about silicon?

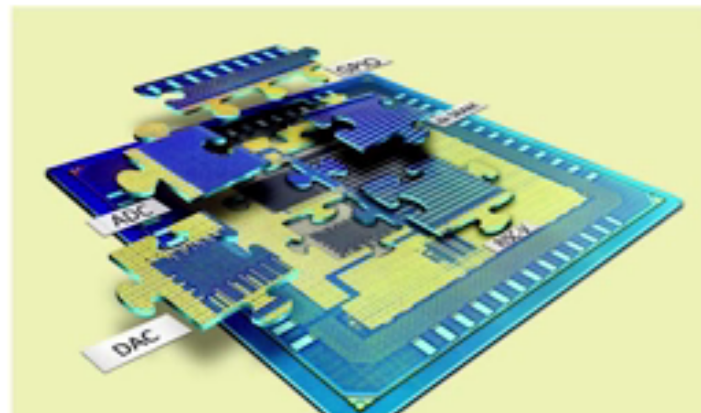


- Crowd Supply update: [A Taste of Chip Design](#)
- Video: [YoPuzzle: mRISC V development platform](#)
- Video: [RISC-V Community needs Peripheral Cores](#)

Good to have an Open ISA. What about Peripheral?



- IP vendors have IP based on previous customer. **Hard to get** a glue-and-play that works for your SoC. → \$\$\$
- There are some std, such as PHYs: USB, LPDDR, PCIe, AMBA
BUT
no for clocking circuitry, biasing, GPIO
For instance a simple Power-on-Reset can hit your pocket, just because!
- Buses IP are out there but expensive.



What about silicon?



- lowRISC:
“creating a fully open-sourced, Linux-capable, RISC-V-based SoC, that can be used either directly or as the basis for a custom design”
- Video: Rob Mullins talking about lowRISC
(RISC-V & Open Source Silicon Event in Munich on March 23, 2017)

What about silicon?



- **FOSSi Foundation**
 - The **F**ree and **O**pen **S**ource **S**ilicon **F**oundation
 - “non-profit foundation with the mission to promote and assist free and open digital hardware designs”
 - “FOSSi Foundation operates as an open, inclusive, vendor-independent group.”

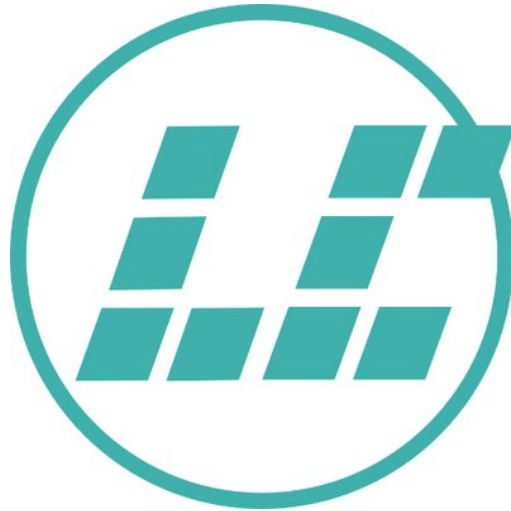
What about silicon?



- Open Source Silicon Design Ecosystem
 - Talk by FOSSi co-founder Julius Baxter

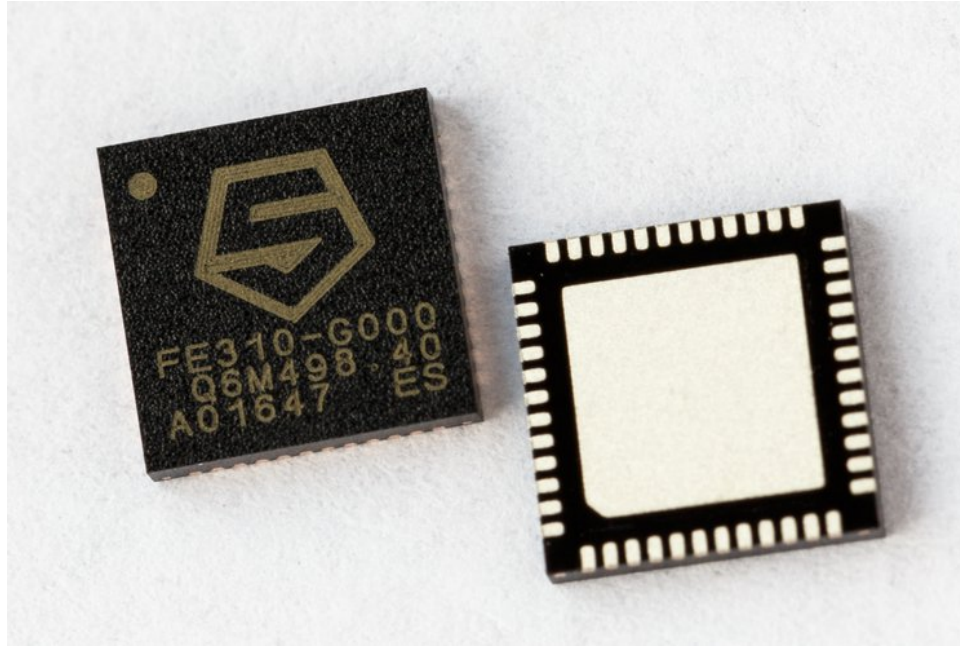


What about silicon?



- **LibreCores**
 - Project of the FOSSi Foundation
 - “**gateway to free and open source digital designs** and other components that you can use and **re-use in your digital designs**”
 - “advances the idea of OpenCores.org”

What about silicon?



- **SiFive**

“founded by the creators of the free and open RISC-V architecture as a reaction to the end of conventional transistor scaling and escalating chip design costs”

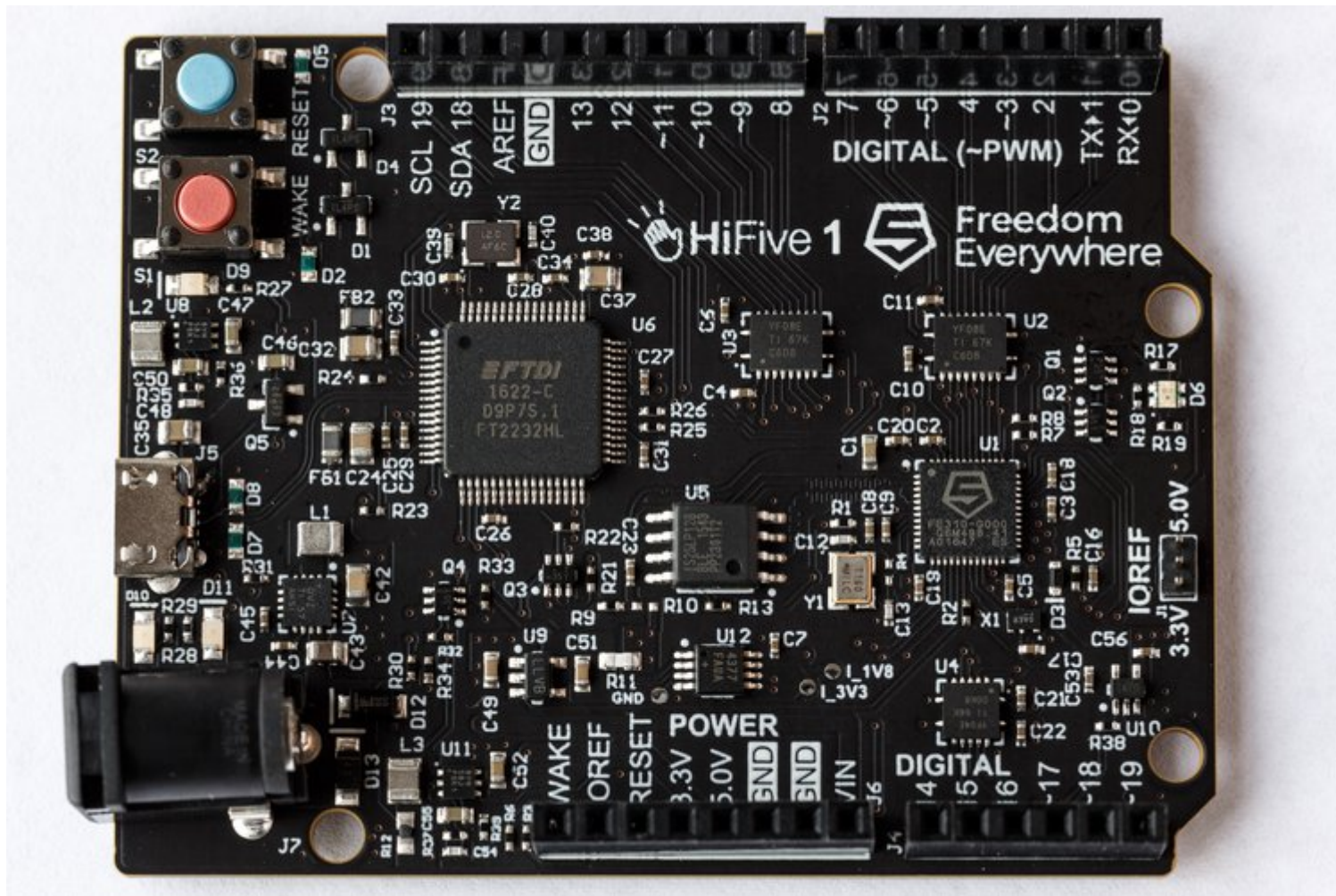
RISC-V ecosystem

- RISC-V Keynote at Embedded Linux Conf
 - March 12th, 2018
 - Yunsup Lee, Co-Founder and CTO, SiFive
 - Designing the Next Billion Chips: How RISC-V is Revolutionizing Hardware



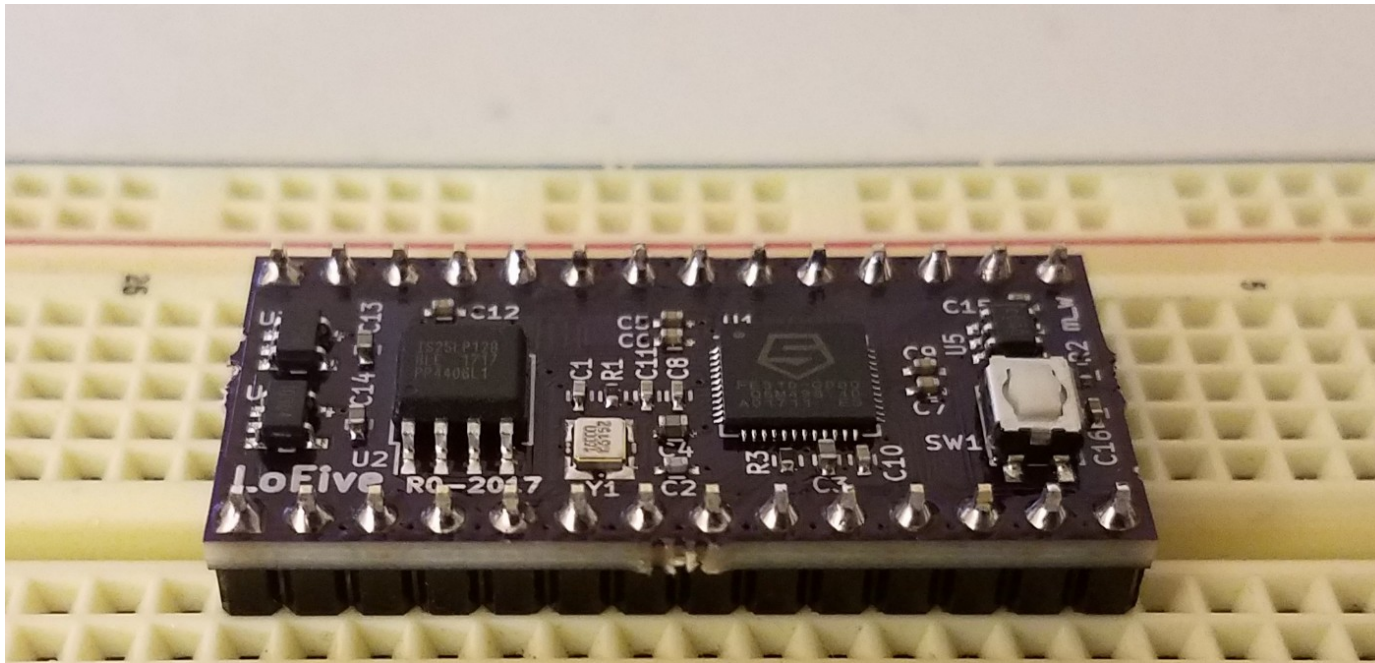
SiFive FE310 microcontroller

- HiFive1: Arduino-Compatible RISC-V Dev Kit



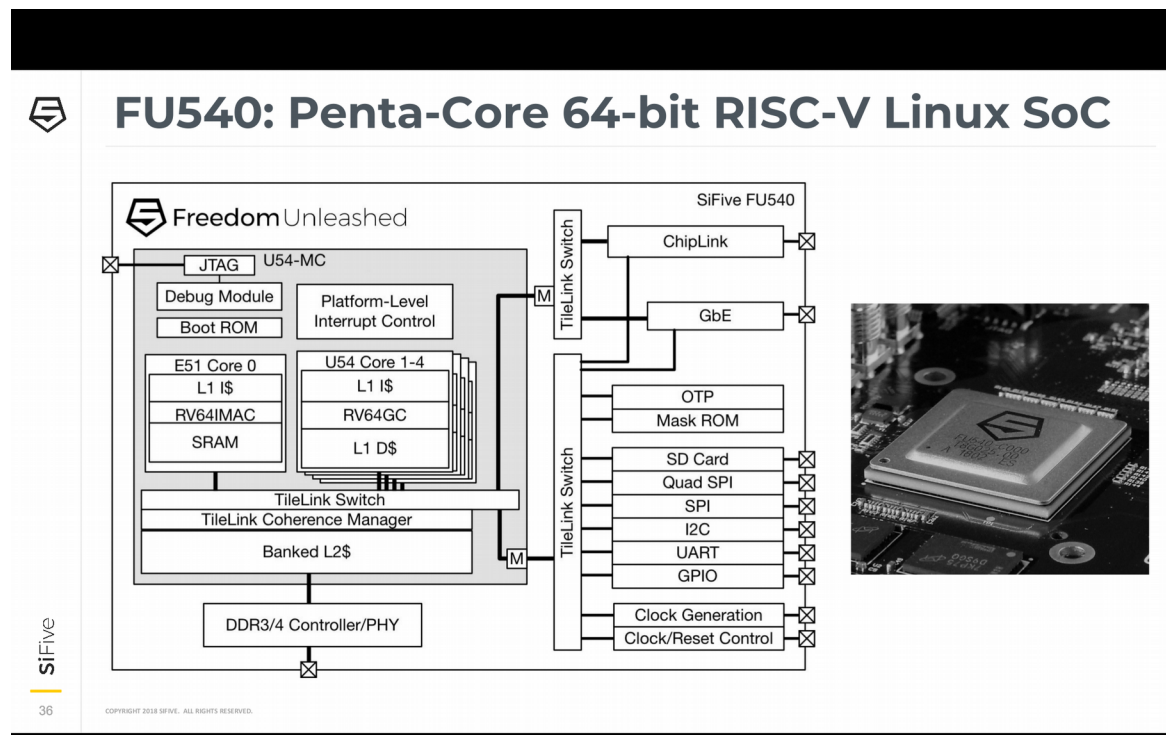
SiFive FE310 microcontroller

- LoFive designed by Michael Welling (*QWERTY Embedded Design*)
- Lower cost eval board for SiFive FE310.
- Open Source Hardware design files
- Sold as group buy on GroupGets



SiFive: Linux on RISC-V

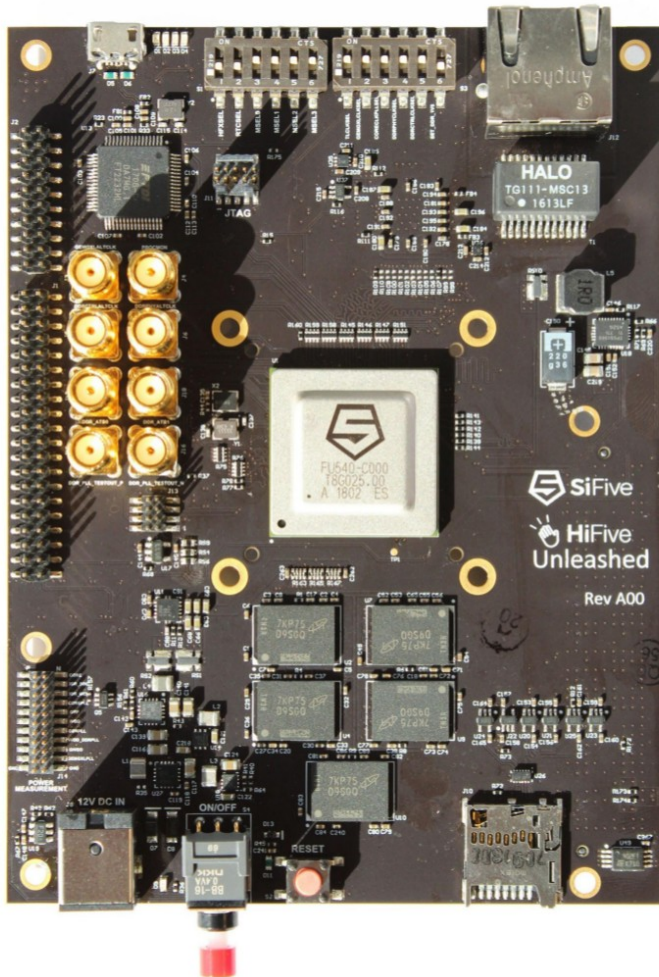
- FOSDEM 2018 talk
 - **YouTube:** “Igniting the Open Hardware Ecosystem with RISC-V: SiFive's Freedom U500 is the World's First Linux-capable Open Source SoC Platform”
 - **Interview with Palmer Dabbelt of SiFive**



SiFive: Linux on RISC-V



HiFive Unleashed



- World's First Multi-Core RISC-V Linux Development Board
 - SiFive FU540-C000 (built in 28nm)
 - 4+1 Multi-Core Coherent Configuration, up to 1.5 GHz
 - 4x U54 RV64GC Application Cores with Sv39 Virtual Memory Support
 - 1x E51 RV64IMAC Management Core
 - Coherent 2MB L2 Cache
 - 64-bit DDR4 with ECC
 - 1x Gigabit Ethernet
 - 8 GB 64-bit DDR4 with ECC
 - Gigabit Ethernet Port
 - 32 MB Quad SPI Flash
 - MicroSD card for removable storage
 - FMC connector for future expansion with add-in cards

OSHW RISC-V Linux board for less than \$100?

- **Goal: Sub-\$100 Open Source Hardware board that can run Linux on RISC-V**
- Possible by ELC 2019?
- Interested in working together?
 - drew@oshpark.com / Twitter: [@pdp7](https://twitter.com/pdp7)
 - create a mailing list?

Thanks

- Suggestions from the [OSHWA mailing list](#):
 - Abram Connelly
 - Andrew Plumb
 - Andrew Quitmeyer
 - Eleftherios Kosmas
 - Marcin Jakubowski

OSHW boards that run Linux?

Please let me know!

drew@pdp7.com Twitter: @pdp7

Create a list on **eLinux wiki**?

These slides are available at:

github.com/pdp7/talks/blob/master/oshw-bof-lfelc-pdx-2018.pdf

Drew Fustini

drew@oshpark.com

@OSHPark / @pdp7

OSH Park Blog



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